# DEEP SEISMIC SOUNDING DATASETS FOR SEISMIC CALIBRATION OF NORTHERN EURASIA

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## ABSTRACT

The University of Wyoming, in cooperation with the Center GEON in Moscow, Russia, is preprocessing and transferring data to the Incorporated Research Institutions for Seismology (IRIS) and the Space and Missile Defense Center Monitoring Research (SMDCMR) facility. This data consists of digital seismic recordings from several unique long-range Deep Seismic Sounding (DSS) profiles using Peaceful Nuclear Explosions (PNEs). As a result of this four-year effort, seismic data from nine major DSS projects using 22 PNEs, several hundred chemical explosions, and recordings of natural seismicity in Northern Eurasia will become broadly available for seismological and nuclear test monitoring research. To date, complete sets of records from the projects QUARTZ, CRATON, KIMBERLITE, and RIFT were delivered to IRIS and SMDCMR, and the data from two RUBY profiles will be delivered October 2003.

DSS PNE profiles were recorded by the Center GEON (the Special Geophysical Expedition at the time) from the early 1970's through late 1980's using 200-400 three-component analog instruments deployed in a grid of lines traversing most of the territory of the Former USSR. Each profile recorded 2-4 PNEs and several dozens of chemical explosions at the same receiver locations. Listening times of up to ~600 sec (after the first arrival) allowed recording of the secondary phases (*S*, *Lg, Pg, Rg*) critical for nuclear test monitoring. The energies of the PNEs ($m_b$ >5) were sufficient for reliable recordings beyond 3000 km, including consistent reflections from the mantle transition zone and several reflections from the core-mantle boundary. Chemical explosions of 5-12 tons yielded reflections from ~100-km depths and were recorded to 300-600-km distance.

DSS PNE data represents an unparalleled source of seismic information about the detailed structure of the upper mantle down to 400-800 km depth. The core PNE data sets cover an intermediate distance range (between 0-3200 km) and bridge the gap between conventional controlled-source seismology and nuclear explosion monitoring seismology. Dense, linear systems of DSS/PNEs observations lead to unusually detailed models of the crust and uppermost mantle over 4000-km long geotraverses. For regional seismic calibration, these datasets provide virtually the only dense three-component recordings of regional phases in aseismic regions of Northern Eurasia.

Numerous publications (primarily by GEON, the Russian Academy of Sciences, the Universities of Wyoming and Saskatchewan, and the Potsdam/Karlsruhe and Copenhagen groups) have presented velocity, reflectivity, attenuation, scattering, and receiver function models inspired by these profiles. As the ongoing discussion of the short-scale heterogeneity of the uppermost mantle shows, PNE waveforms still contain a wealth of information that needs to be recovered by modern numerical analysis. When made broadly accessible for nuclear test monitoring research, the datasets should become very important for seismic calibration and for the development of transportable seismic discriminants in Asia. From a broader scientific perspective, the digitized DSS recordings and models of the upper mantle could provide ideal reference and calibration data sets for the detailed structure of the upper mantle targeted by the recently funded USArray program.

## OBJECTIVE

Over the past three decades, Russian scientists acquired a network of dense, linear, long-range, three-component Deep Seismic Sounding (DSS) profiles using conventional and Peaceful Nuclear Explosions (PNEs) over a large territory of Northern Eurasia. These historic data provide unique opportunities to calibrate seismic nuclear discrimination techniques by studying regional wave propagation through complex continental lithospheric structures.

The objective of this four-year effort is to digitize, verify, edit, and make broadly available through IRIS and SMD CMR data repositories a significant part of the unique collection of DSS PNE datasets currently stored on analogue magnetic tapes at Center GEON. The data processed and transferred to IRIS over this project's four years will include 22 PNEs recorded by nine major seismic projects (Figure 1). As a result of this work, we will deliver to the seismological and seismic Comprehensive Nuclear-Test-Ban Treaty (CTBT) monitoring community a set of unparalleled recordings of a large number of nuclear explosions recorded across a grid of propagation paths to the distances of ~3,000 km across the Northern Eurasia.

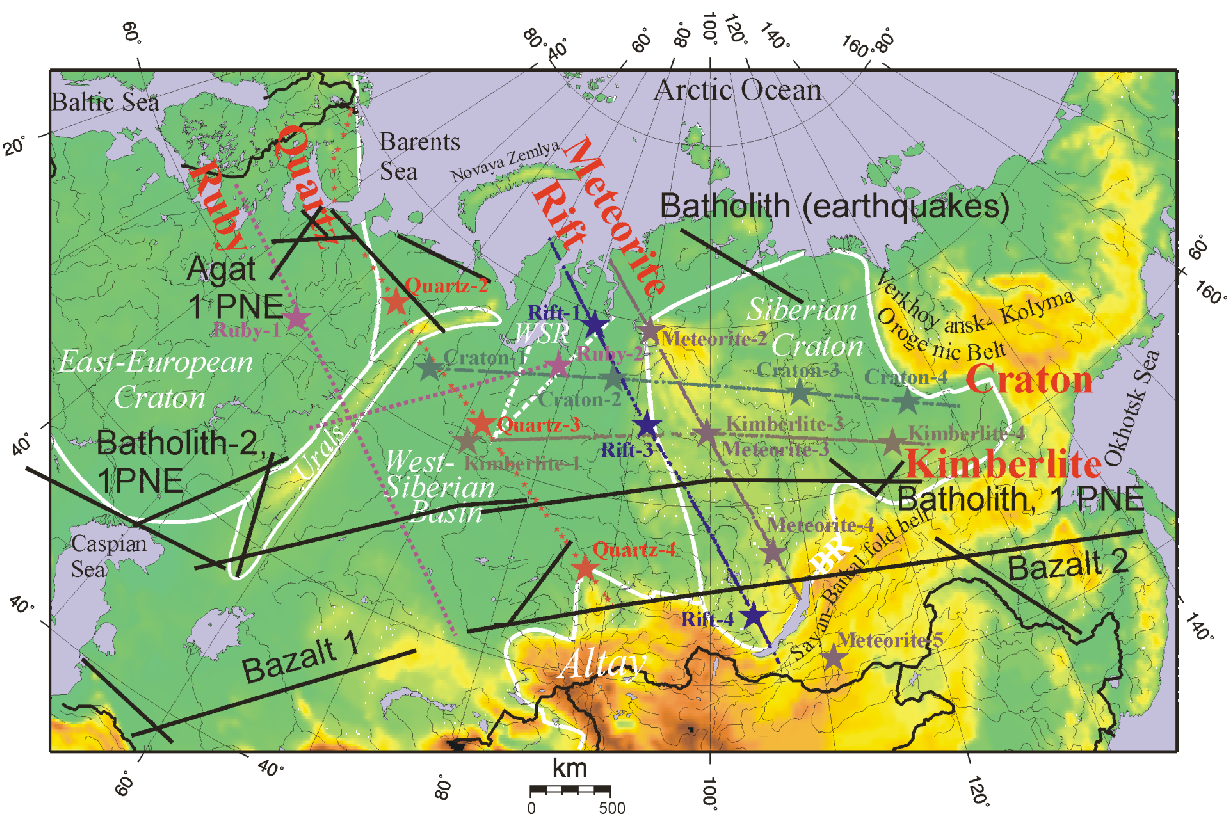


**Figure 1 Nine DSS PNE projects to be delivered to IRIS as a result of this project. The data from profile QUARTZ and the PNEs from profile CRATON have already been delivered to IRIS. Colored lines and stars indicate the profiles and PNEs that have been digitized previously, black lines are the profiles to be digitized in this work. The coordinates and other parameters of the PNEs were reported by Sultanov et al. (1999), and the PNEs were also recorded by numerous permanent and temporary seismographic stations worldwide. Major tectonic units are indicated. Note the extent of systematic, continuous profiling, with PNEs detonated at the nodes of a 2-D recording grid. Note that the profiles cover a vast asiesmic area that would be difficult to calibrate by other means.**

## RESEARCH ACCOMPLISHED

This is an update of our last year's report (Smithson et al., 2002) on a four-year project for digitization and transcribing a significant part of the DSS PNE datasets from the Former Soviet Union. DSS PNE data have been widely recognized as a still unparalleled source of seismic information about the detailed structure of the upper mantle down to 400- to 800-km depth and in some cases to the Earth's core. The PNE data sets of the DSS program cover an intermediate distance range between 0–3,200 km bridging the gap between the conventional controlled source, earthquake, and nuclear–explosion-monitoring seismology. The dense, linear systems of PNEs and chemical explosions allow obtaining unusually detailed models of the crust and uppermost mantle over 4,000-km long geotraverses. Because the Northern Eurasia is largely aseismic, these datasets provide virtually the only dense three-component recordings of regional phases in aseismic regions of Northern Eurasia.

PNE yields were between 7–23 kton providing reliable seismic recording throughout the full recording ranges (Figure 1). Continuous and often reversed PNE recordings allow observations of seismic phases diving to depths of ~800 km (e.g., Egorkin et al, 1987; Ryaboy, 1989; Kozlovsky, 1990; Morozova et al., 1999). On a typical PNE profile, 3–4 nuclear explosions were recorded at up to 400 of three-component seismograph stations with nominal spacing of 10 to 15 km. About 50–80 chemical explosions (typically, each 3,000–5,000 kg) per profile were also recorded to enable interpretation of crustal and uppermost mantle structures. The locations, depths, yields, times of the PNEs, and characterizations of the source conditions were recently reported by Sultanov et al., (1999). The data are being digitized at Center GEON, Moscow, and preprocessed and edited at the University of Wyoming.

DSS profiles cross a variety of contrasting tectonic structures in Northern Eurasia and their studies have resulted in detailed images of the crust and uppermost mantle (Yegorkin, 1992). Some of the recent interpretations were performed by Egorkin and Mikhaltsev (1990), Mechie et al. (1993, 1997), Cipar et al. (1993), Priestley et al., (1994), Ryberg et. al. (1995, 1996), Schueller et al. (1997), Lorenz et al. (1997), Morozov et al. (1998a), and Morozova et al. (1999). The interpretations of the profile QUARTZ (Figure 2) by the University of Wyoming utilized the full spectrum of seismic data, including refractions and reflections from all 51 explosions of the dataset, lithospheric multiples, crustal-guided phases, seismic attenuation (Morozov et al., 1998b), coda amplitude decay (Morozov and Smithson, 2000), receiver functions (Morozov et al, in press), and empirical travel-time regionalization (Morozov et al., in final preparation). Using travel time, amplitude, and attenuation data, this study resulted in unusually well constrained images of crustal and mantle heterogeneity (Schueller et al., 1997; Morozov et al. 1998a, 1998b; Morozova et al., 1999). PNE data served as a basis for a new class of stochastic models of the uppermost mantle (e.g., Ryberg et al., 1995; Enderle et al., 1997), which, however, also resulted in a significant controversy (Morozov et al., 1998a; Morozov, 2001) and are being actively debated at present. The datasets contain spectacular and nearly continuous, 3-component recordings of regional phases (Figure 3) that still hold great potential for nuclear test monitoring research (Morozov et al., 2003).

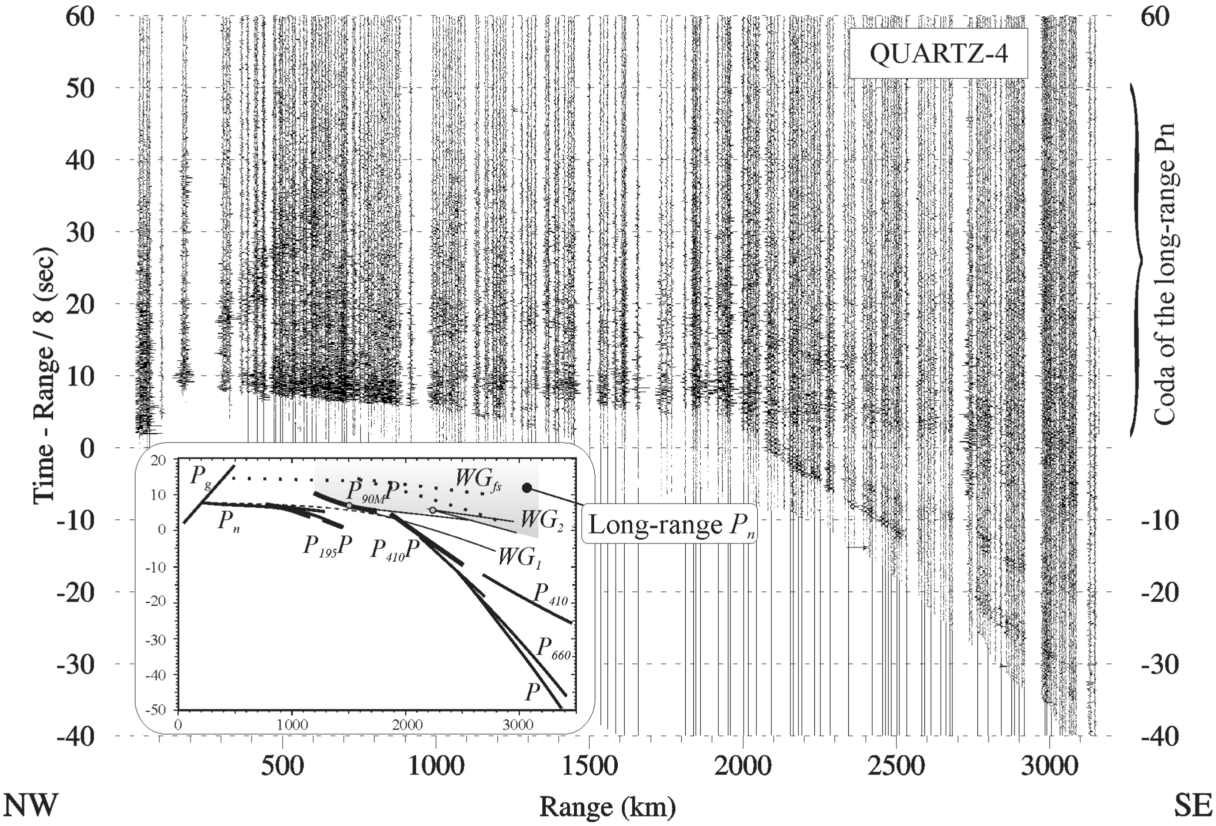


**Figure 2. Vertical component record from PNE QUARTZ-4 (Figure 1). Inset shows a sketch of seismic phases identified in the wavefield. Note the free-surface and Moho *P*-wave multiples (*PP*, or whispering-gallery modes) labeled *WGfs* and *WG*, respectively. These phases were interpreted as caused by strong scattering within the uppermost mantle (Ryberg et al., 1995); however, in another interpretation, they may be a result of a strong velocity gradient and mantle layering beneath the East European platform and the southern part of the West Siberian Basin (Morozov, 2001). Both of these inferences might have significant implications for nuclear test monitoring along the critical NW-SE paths across the East European Platform.**

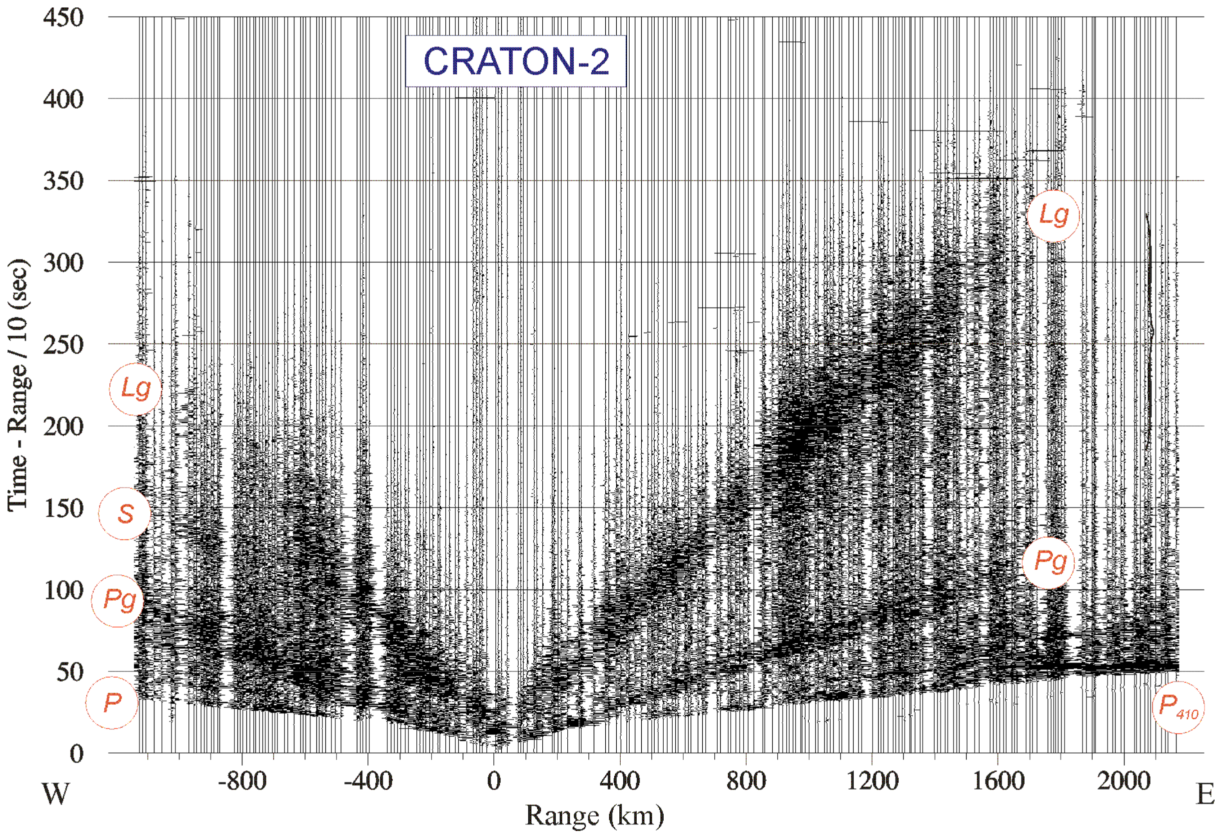


**Figure3. Vertical-component record from PNE CRATON-2 (Figure 1). Note the continuity of arrivals extending to the transition zone discontinuities. Also note the strong *Lg* and *Pg* propagating to the ranges exceeding 1600 – 1700 km, and the differences between the character of *S* wave and *Lg* in two directions from the PNE. *Lg* is very strong east of the shot point (under the Siberian Craton) whereas the mantle *S*-wave propagates efficiently to the west, under the West Siberian basin (Figure 1).**

To date, we have delivered to IRIS and SMD CMR the digitized seismic data from profiles QUARTZ, CRATON, KIMBERLITE, and RIFT (Figure 1). At the early stages of the project, we experienced delays in chemical shot data deliveries from the Center GEON; however, at present, we are back on schedule, and GEON event provided us with the data from AGATE ahead of schedule (see the table below). On request from Center GEON, we also changed the order of processing of the projects by moving the profile METERORITE to the end of the project and advancing the delivery dates for the new datasets (AGATE, BATHOLITH, and BAZALT). The updated schedule for current and further planned data deliveries is given in Table 1 below.

Table 1. Revised planned and actual data deliveries as of July 2003.

| # | Data set | Raw data delivery from GEON to UWyo (months) | | Edited and reduced data delivered to IRIS DMS (months) | |
|---|---|---|---|---|---|
| | | *planned* | *actual* | *planned* | *actual* |
| 1 | QUARTZ | Already delivered | - | 12/2001 | 12/2002 |
| 2 | CRATON | 02/2002 | 10/2002 | 08/2002 | 11/2002 |
| 3 | KIMBERLITE | 05/2002 | 11/2002 | 11/2002 | 11/2002 |
| 4 | RIFT | 08/2002 | 11/2002 | 05/2003 | 07/2003 |
| 5 | RUBY | 02/2003* | 02/2003 | 10/2003 | |
| 6 | AGATE (5 profiles) | 08/2003 | 06/2003 | 05/2004 | |
| 7 | BATHOLITH-1,2 | 04/2004 | | 11/2004 | |
| 8 | BAZALT-1,2 | 11/2004 | | 06/2005 | |
| 9 | METEORITE | 03/2005* | | 11/2005 | |

*Only chemical explosion data sets need to be delivered to UWYO

## CONCLUSIONS AND RECOMMENDATIONS

Preliminary examination of the newly obtained Russian PNE records from the DSS PNE profiles demonstrates that the data provide valuable information for the analysis of the propagation of $L_g$ and other phases for their use in nuclear test monitoring and calibration studies. When made broadly accessible for nuclear test monitoring research, the datasets will boost research on seismic calibration of the region and on transportable seismic discriminants in Asia. Greater availability of the unique PNE recordings would foster current research on several DoD-sponsored projects and facilitate extension of such research in the future. From a broader scientific perspective, the digitized DSS recordings and models of the upper mantle could also provide ideal reference and calibration data sets for the detailed structure of the upper mantle targeted by the recently funded by the NSF Earthscope program.

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